Ultra High Brightness Laser Diode Arrays for Pumping of Solid State Lasers

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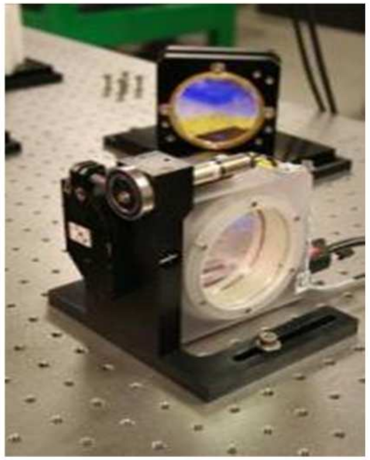
Quantel Laser Diodes

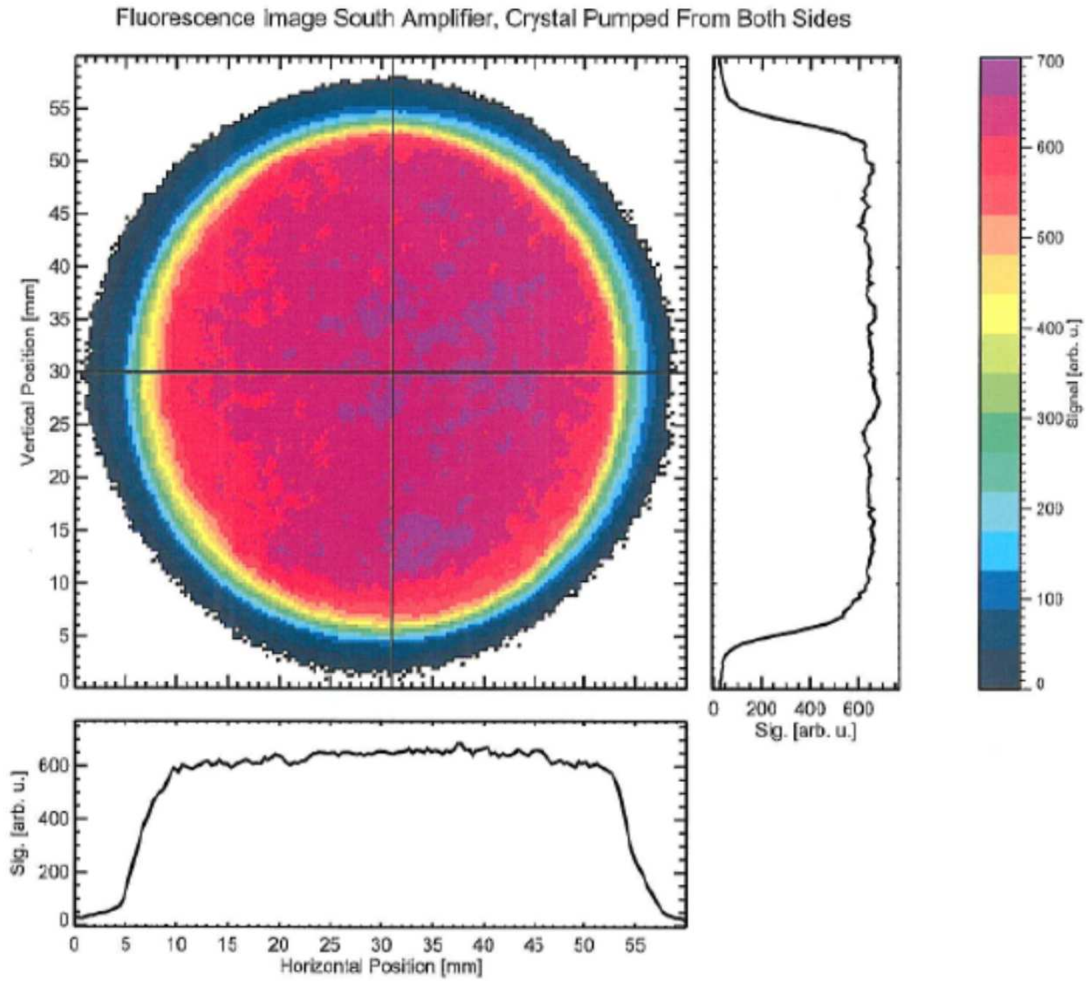
Medical Lasers Business Unit

Scientific and Industrial Lasers B.U.

- Industrial Lasers
- Pump Lasers (Ti:Sa Oscillators, Amplifier)
- Space Born & Defense Lasers
- Mega Joule Laser (Pre-Amplifier)
- Fiber Lasers
- High Power Laser Diodes

Ti:Sa pumping: a product range from Ti:Sa oscillator to power amplifier



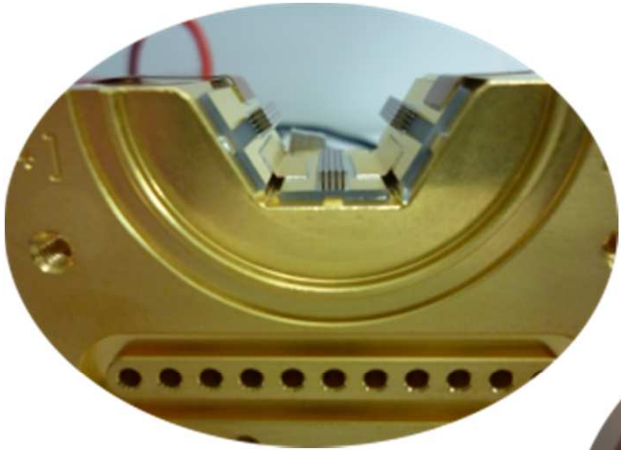


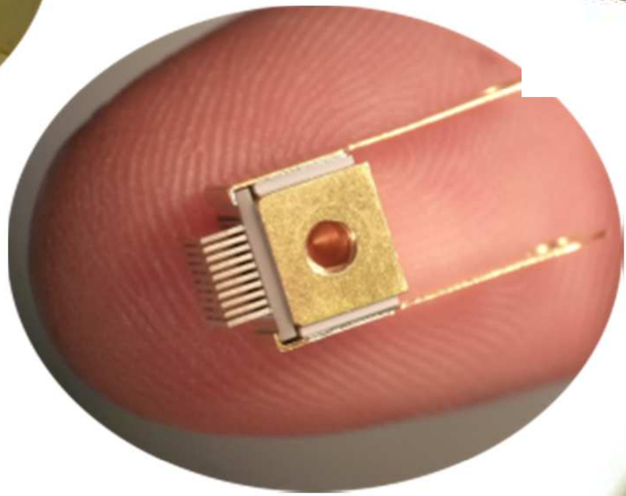
Courtesy of Rutherford Appleton Laboratory (UK)

June 2012: Installation of the Pre-Amplifier in Bordaux

1J class Laser Amp. including homogenizer, numerical spatial & temporal beam profilers

The Other Extreme of the Size Scale….
…..Diodes





Quantel laser diodes

The Other Extreme of the Size Scale….
…..Diodes

Pumping of…

…Industrial Lasers (e.g. Quantel's "Centurion")
- *Flat Panel Repair*
- *Solar Cell Manufacturing*

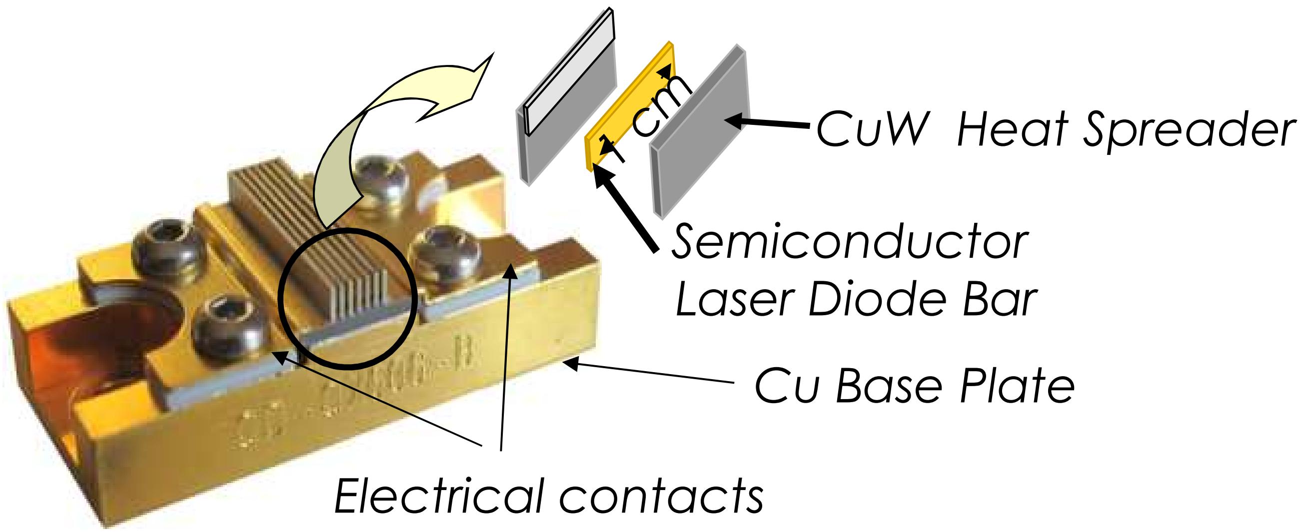
…Defense Lasers
- *Targeting Pods*
- *Telemeters*

…Space Born Lasers
- *Lidar*
- *LIBS*

Standard Packaging

- « Stack » = assembly of several High Power Diode Bars

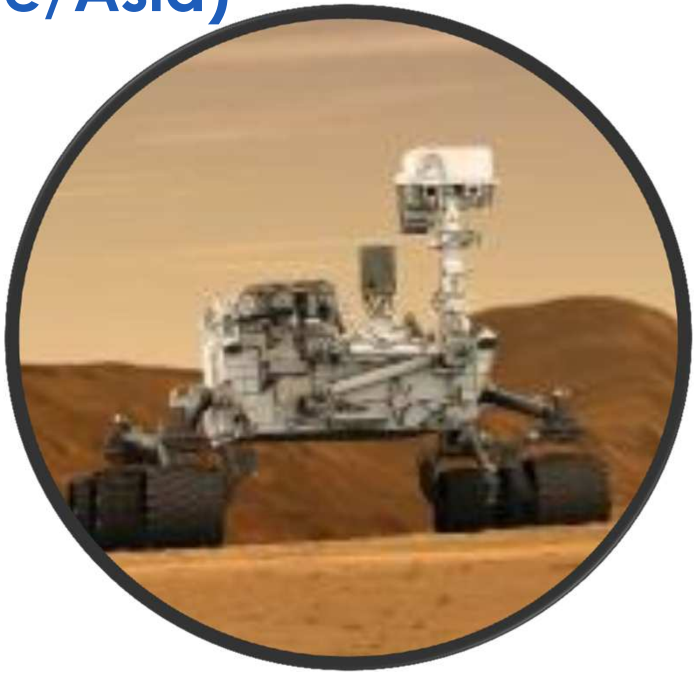
➔ Pumping of Solid State lasers: Typ. 808 nm, 880 nm, 940 nm, 980 nm



- Operating conditions = Pulsed Mode: Typically 2% Duty Cycle
- Output Power: Up to 500 W per bar (1kW for short pulse)

Qualified for….

- Defence Applications (USA/Europe/Asia)
- NASA Space Programmes
  - LOLA (Moon Altimeter)
  - → QLD Diodes flying around the moon
  - MSL 09 ("Chemcam"):
  - → Curiosity operating on Mars
  - → LIBS Laser pumped by QLD Diodes



- ESA Space Programmes
  - ADM/AEOLUS
  - ATLID/Earth Care
- JAPAN Space:
  - Jaxa, NEC..

Quantel laser diodes

HECDPSSL: Requirements for Diode Pump Sources

Diode Stack Performance:

- High Brightness and Compactness
- Low spectral width
- High Efficiency
- Lifetime

Price: $/Watt

Assembling of stacks into1 and 2 dimensional arrays

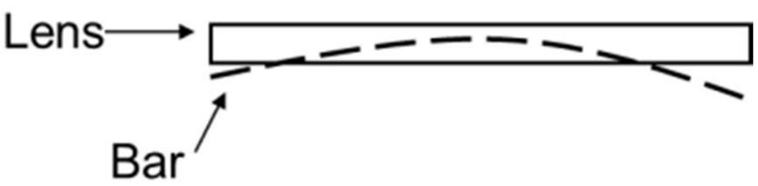
- Densely packed (compact assembly)
- Small gaps between stack to avoid “optically dead zones”
- Cold plates capable to extract waste heat

Diode-Driver

- Compliant with diode performances (e.g. increasingly high drive currents)
- Diode Protections
- Efficient

High Brightness: FA Collimation

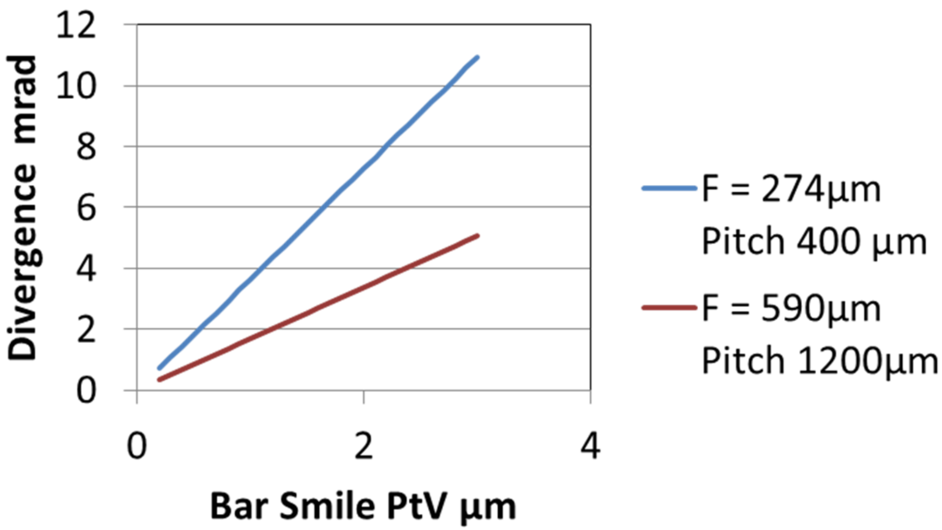
Collimation by micro lenses



Smaller Bar to Bar Pitch

→ Shorter Focal Length

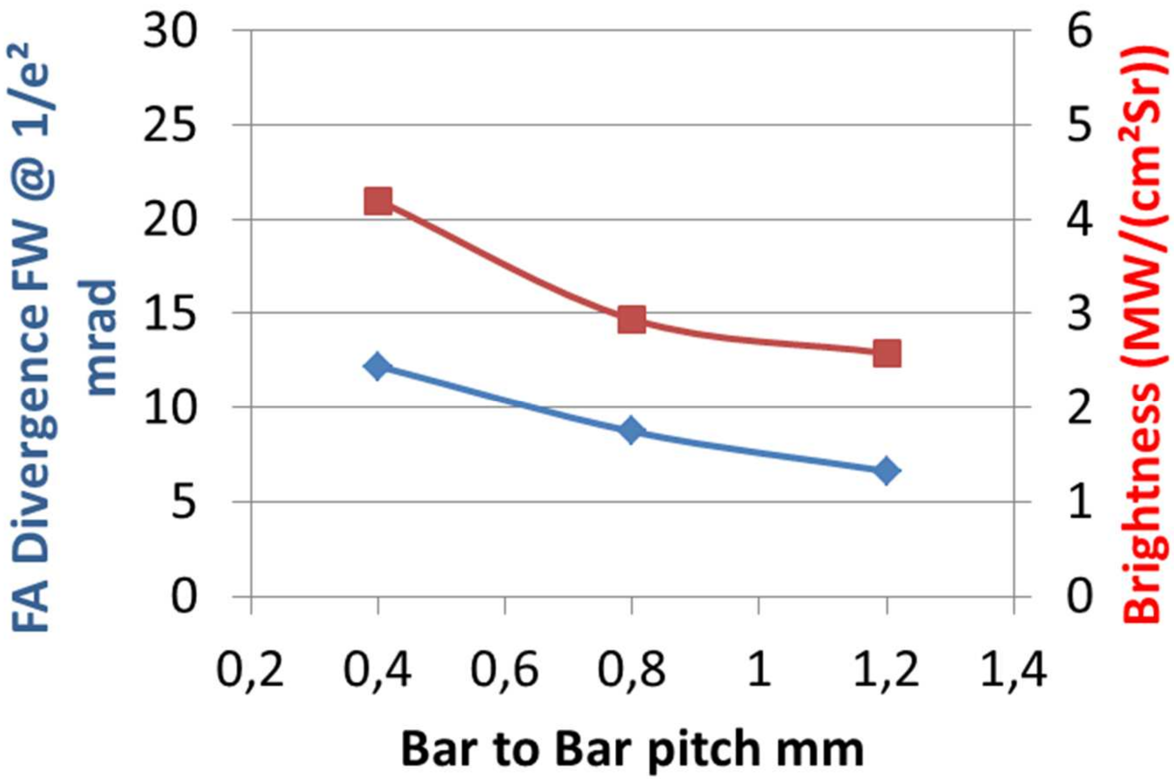
→ More Sensitive on Bar Smile



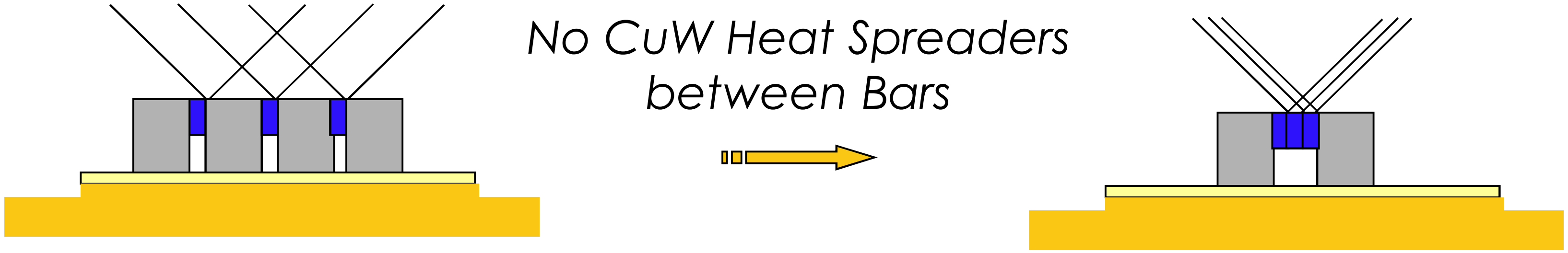
High Brightness: FA Collimation

- Improvements in packaging (mechanical tolerances):

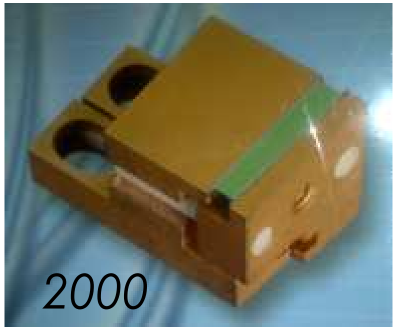
➔ Smaller Pitch ➔ Higher Brightness/ More Compact Stack



Further Reducing Bar Pitch: "Auto-Stack"



- **QLD Patent Pending (2000)**



- **<u>Year 2000:</u> "Low Efficiency" Bars/ Short Cavity**

→ **Limited to low DC (0,3%)**

→ **Low Power per Bar (100W)**

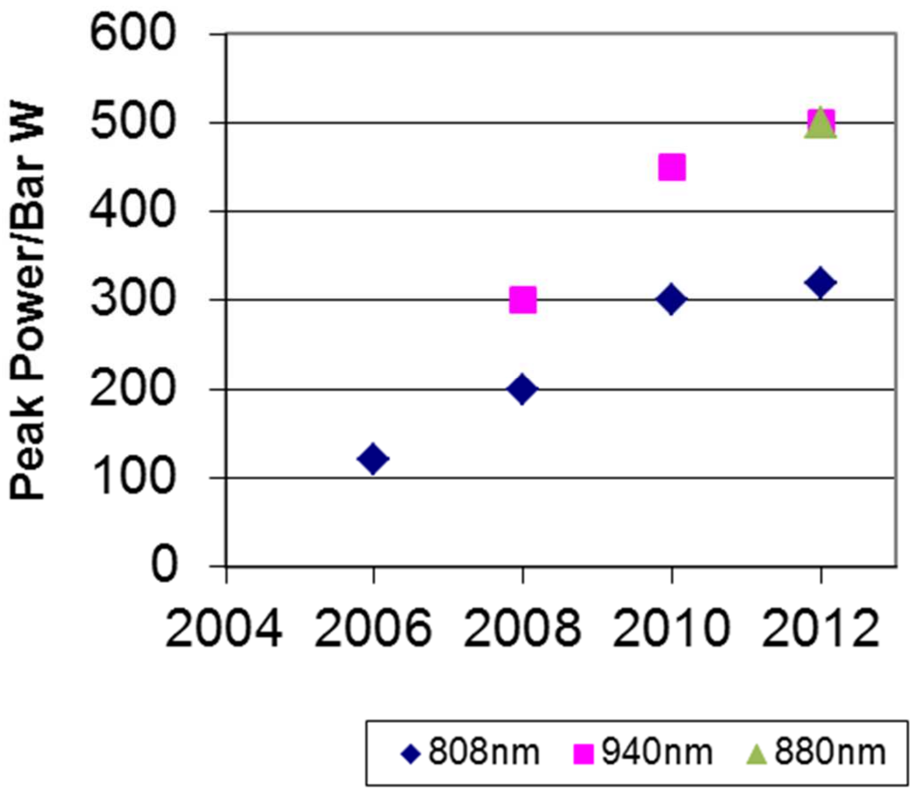
- **<u>Year 2012:</u> Much Higher Efficiencies/ Longer Cavities**

→ **Up to 2 % DC**

→ **Up to 200W / Bar**

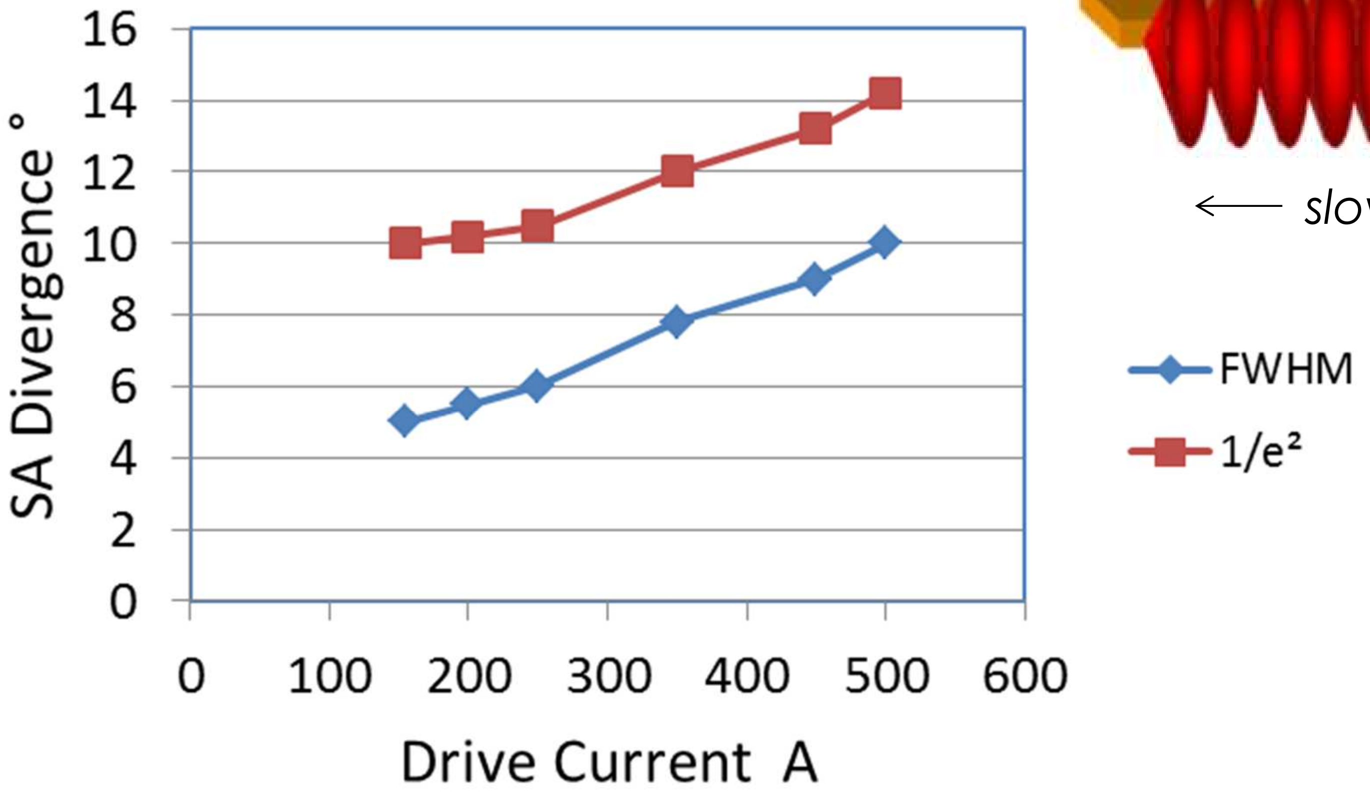
➔ **Main Issue: Homogeneous Heat Extraction- Spectral Width**

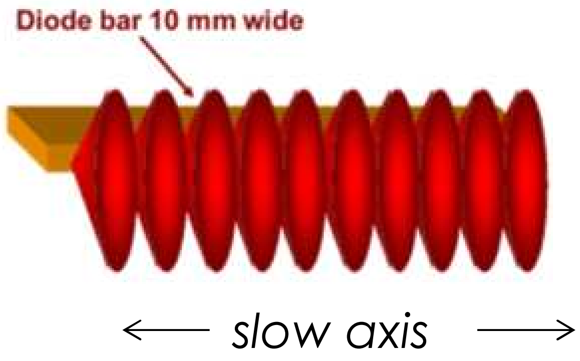
High Brightness: Power per Bar



- Fast progress < 2010
- Slowed down > 2010
  - High Power could not be used, requires high current diode drivers
  - Requires improvements on the semiconductor (facet coating, passivation)

High Brightness: Drive Current increases SA Divergence



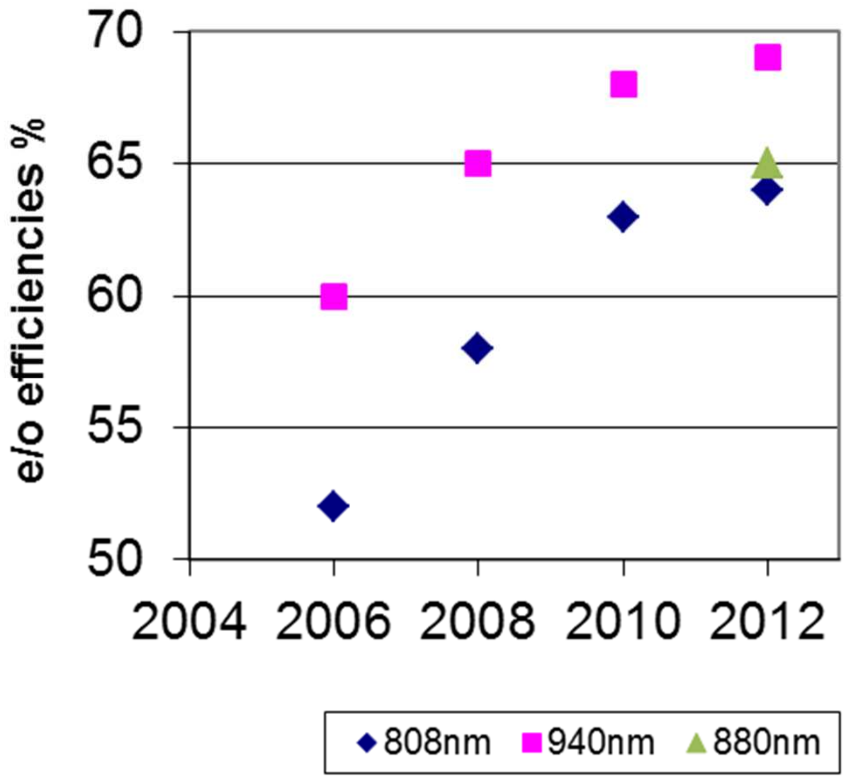


- Drive current increases SA divergence
- Longer cavities can reduce the effect

e/o Efficiencies

- Low Spectral width, high power, small pitch….

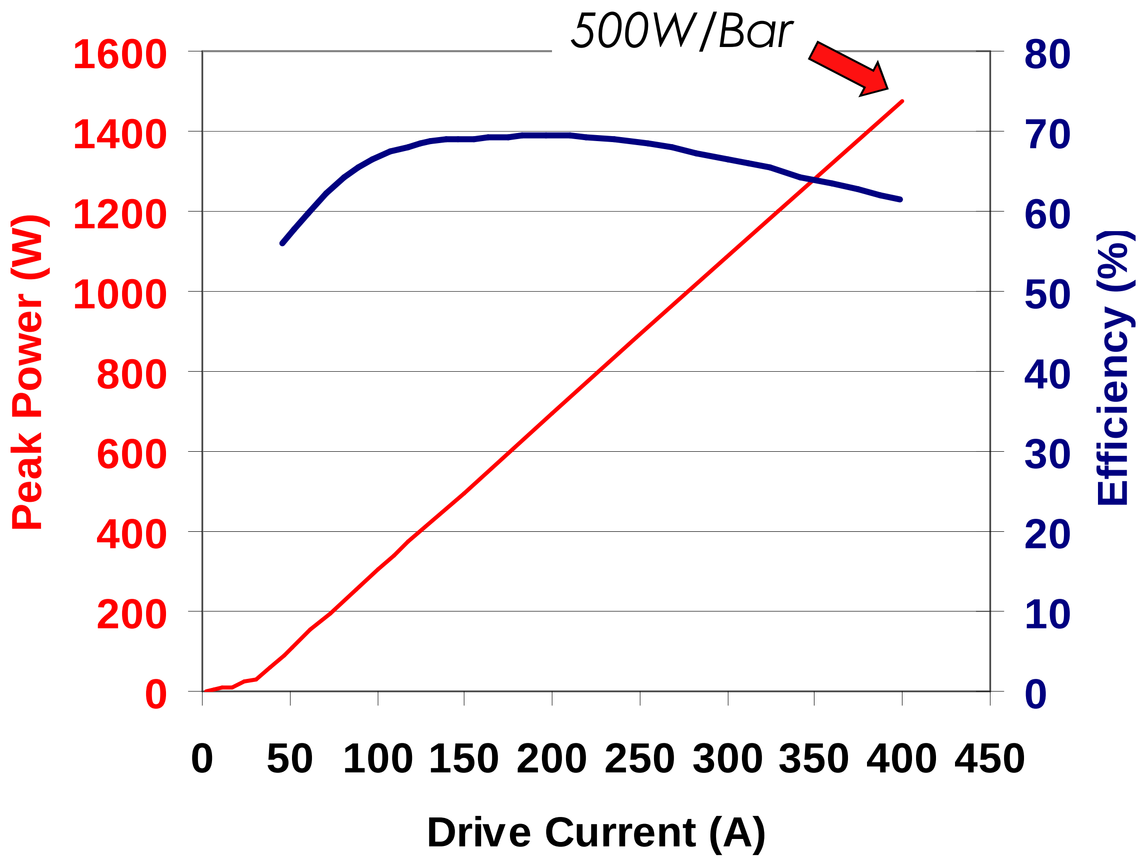
High e/o efficiencies are crucial



- Very good progress but increasingly difficult to go further
  - Complex optimization (high power, low divergence, high efficiency)

Stacks @ 940 nm

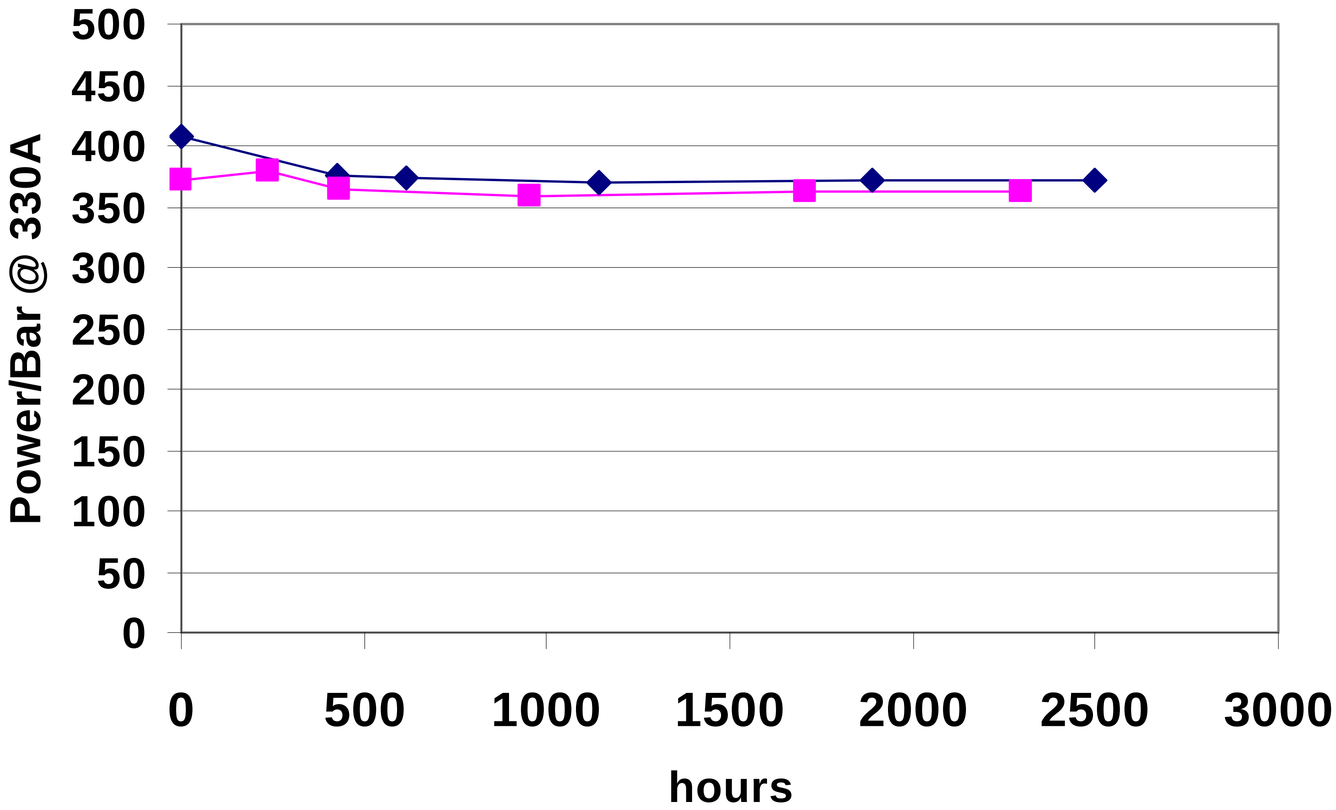
- 3 Bars Stack
- 1.2mm Pitch
- 25°C
- Pulse: 1ms
- 10Hz



- Maximum Efficiency ~70% @ 270W/Bar
- High Efficiency ➔ Reduced « Waste Heat »➔ Increasing Packaging Density (smaler pitch) ➔ higher brightness

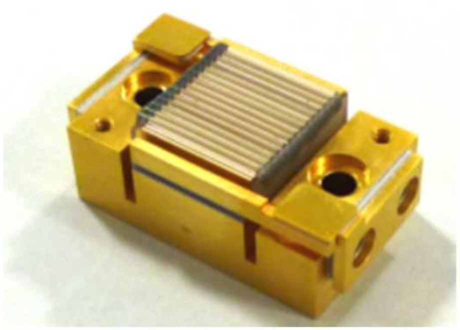
Aging at 400W/Bar 940 nm

- Aging 370A-400W/Bar, 1 ms/ 10Hz, 35°C, 3 bars stack



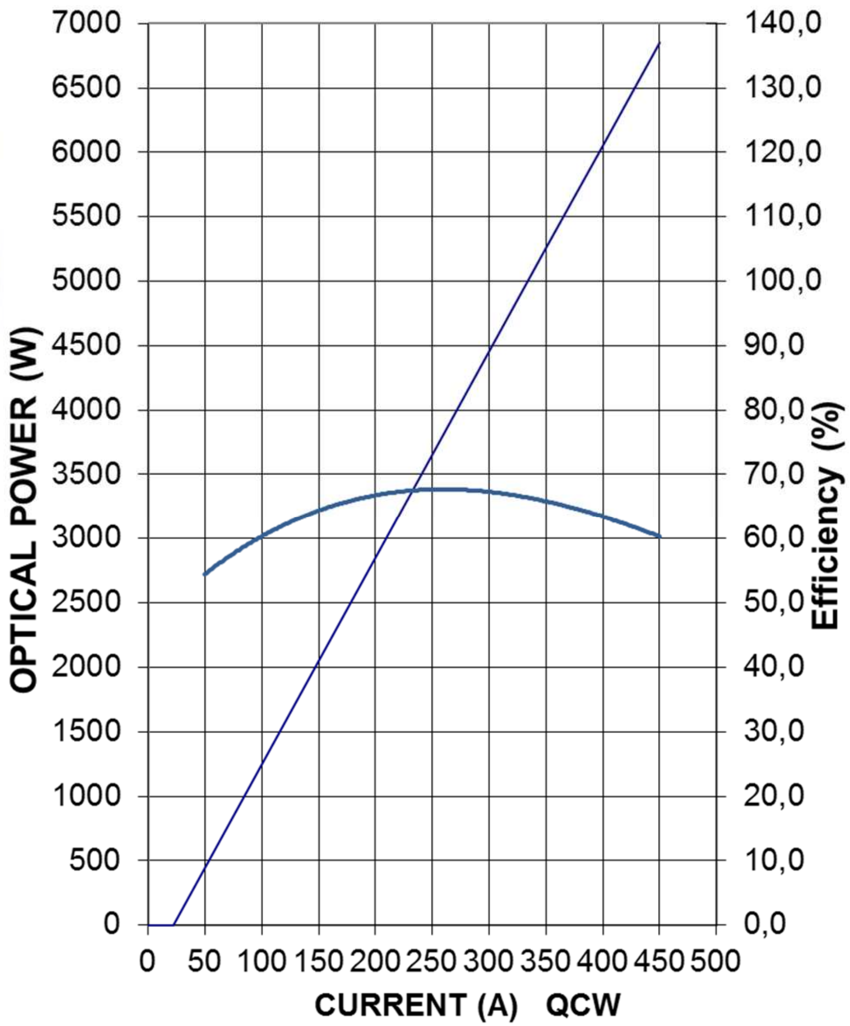
➔ Stable operation at 400W/Bar

Stacks @ 940 nm/ 980 nm



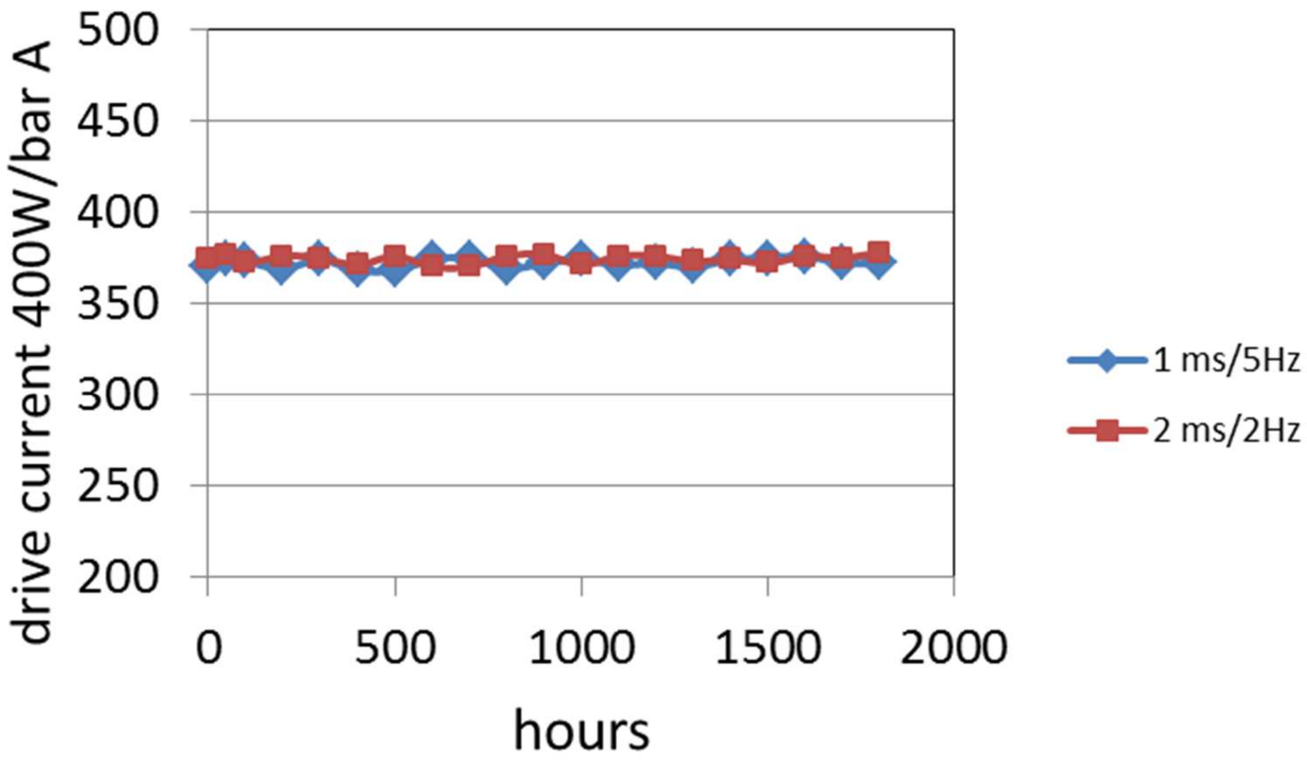
- 14 Bar stacks, QCW: up to 2ms
- 940 nm or 980 nm
- Up to 500W/bar (7 kW)
- > 65 % e/o efficience

- 800 µm bar to bar pitch
- FA divergence: < 0,5° @ $1/e^2$
- 1 cm^2 emitting surface



Aging 980 nm

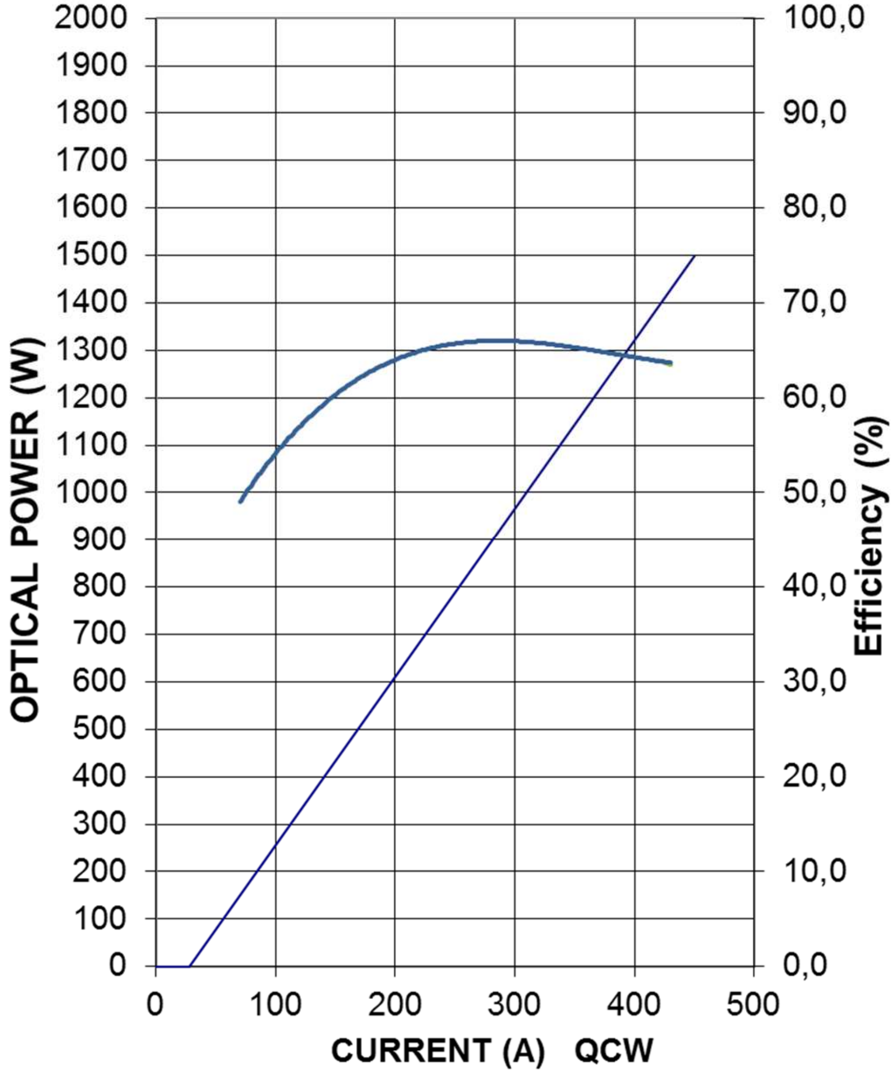
- Stack 14 bars
- 800µm pitch
- 400W/bar
- 25°C



Stacks operating at 880nm

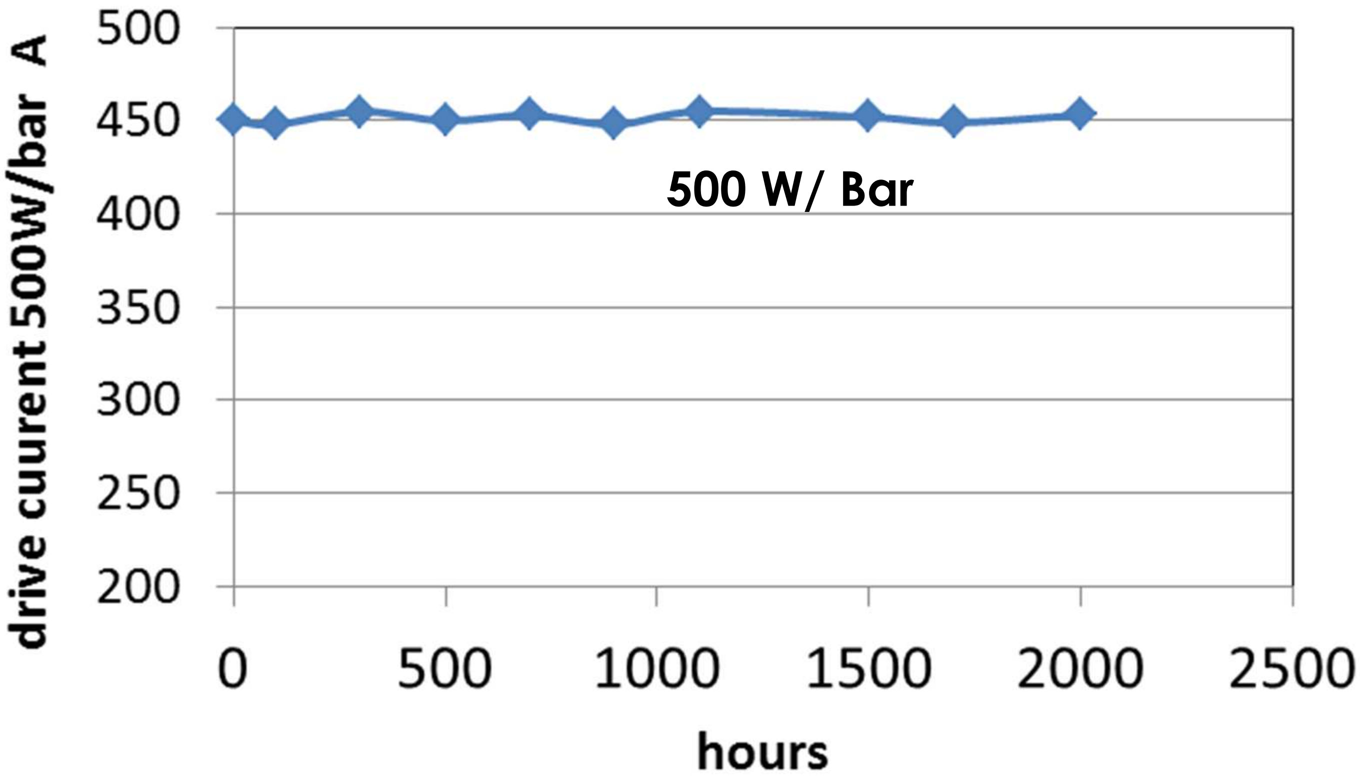
- 3 Bars Stack
- 400 µm pitch
- 25°C
- Pulse: 300µs
- 20Hz

- Up to 500W per Bar
- > 60% efficiency @ 500W

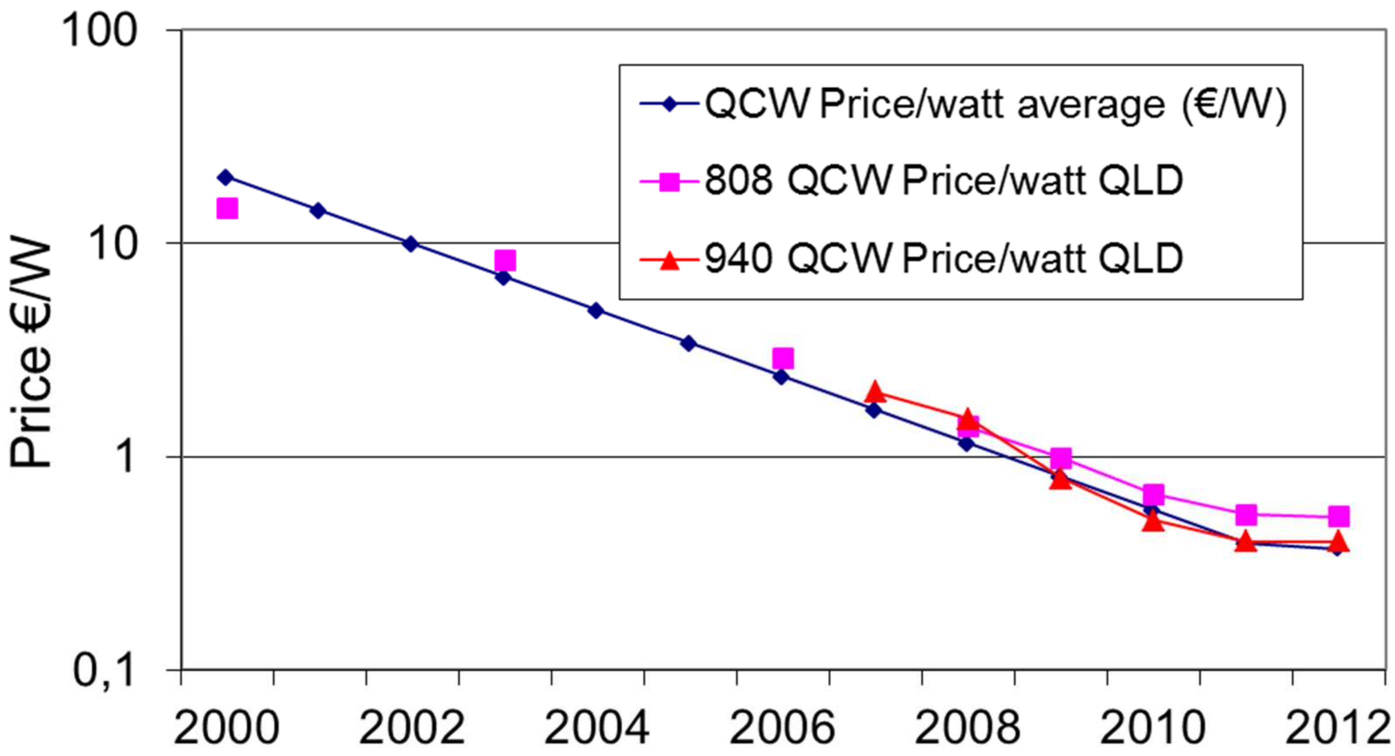


Aging: 880 nm

- 3 Bars Stack
- 400 µm pitch
- 25°C
- Pulse: 300µs
- 20Hz

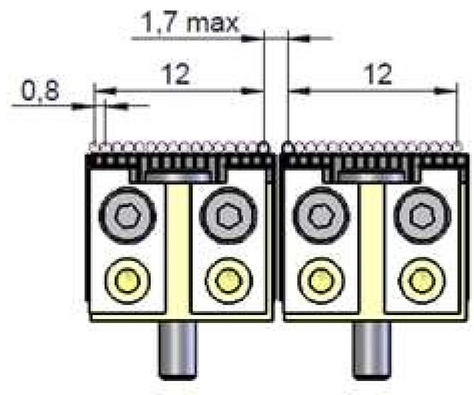


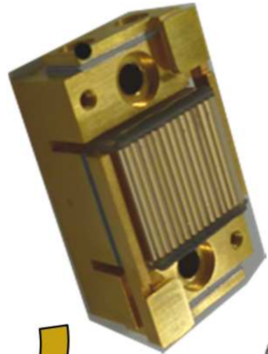
Price of Diodes



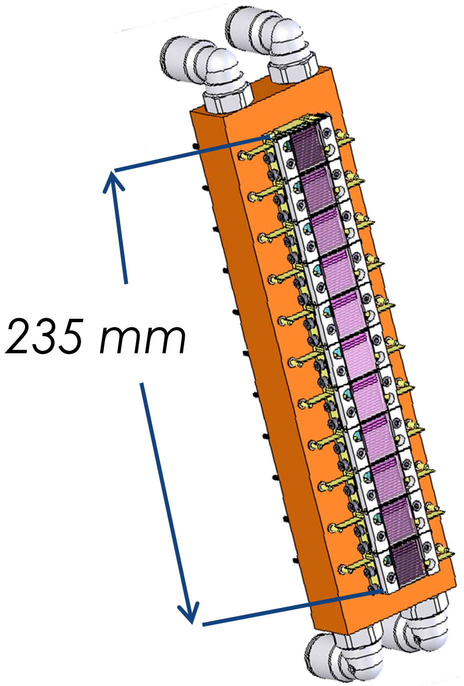
- **Further Reduction Expected from:**
  - Increasing volumes (Semiconductor and Packaging)
  - Higher Power per Bar

Cold Plate for 1D Arrays



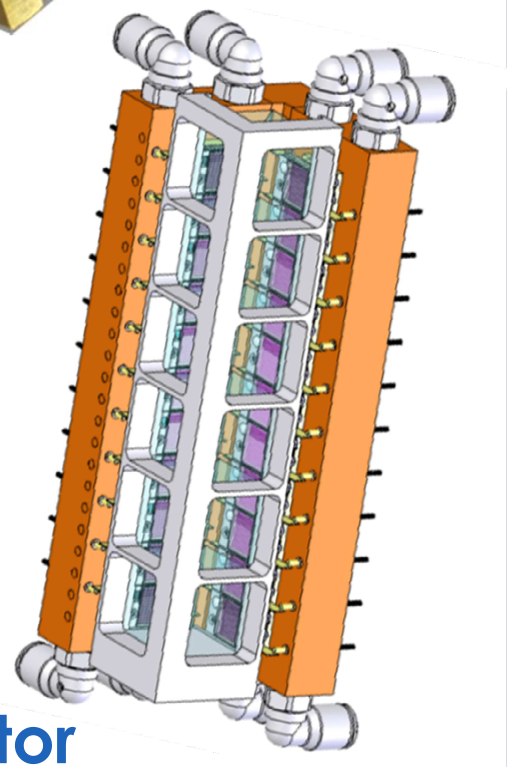


7 kW



up to 110 kW
out of 235mm

180 kW

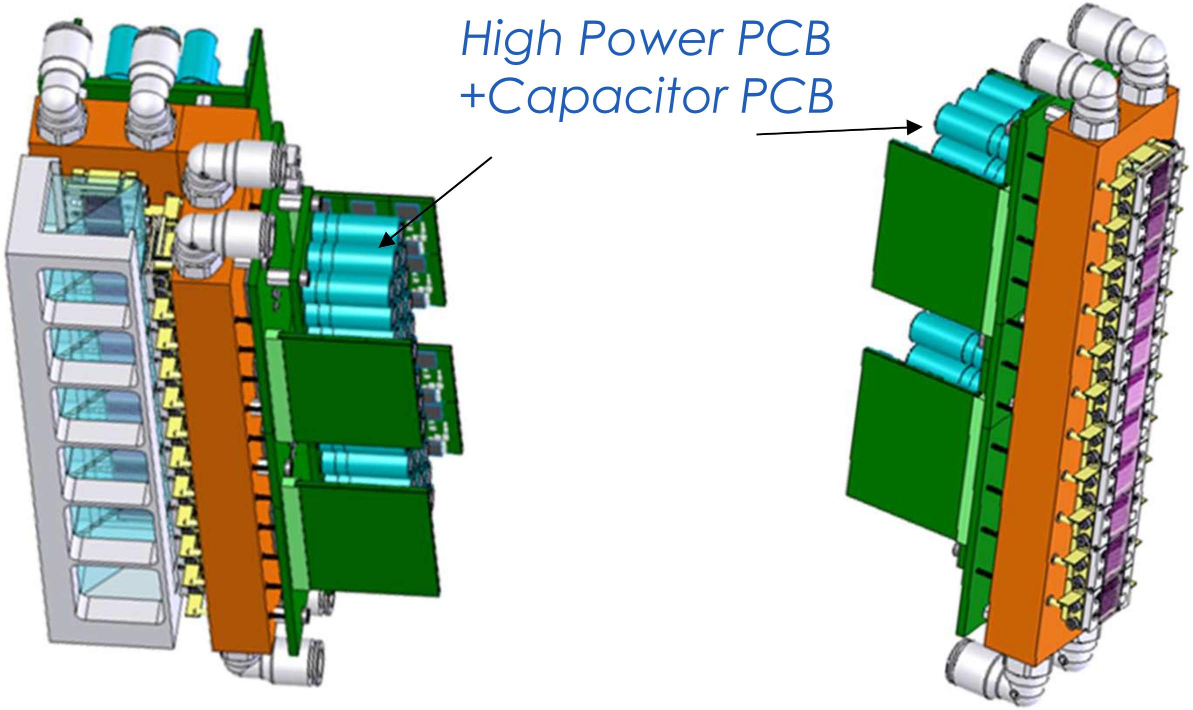


Small Gap between Stacks

➔ 90% Optical Filling Factor

Dealing with High Drive Currents > 500 A

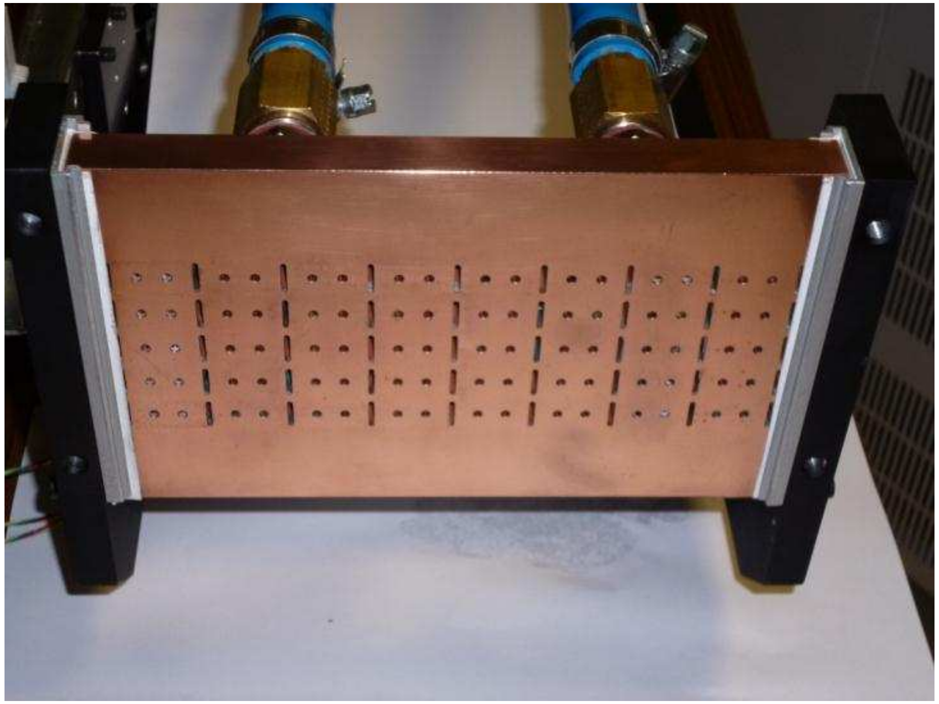
- **High Power Bars ➔ Switching High Drive Currents ➔ Cabling ?**



- **Integration of High Power Driver PCB on stack ➔ Short connections for higher peak Currents. Electromagnetic field reduced.**

Cold Plate for 2 D Arrays

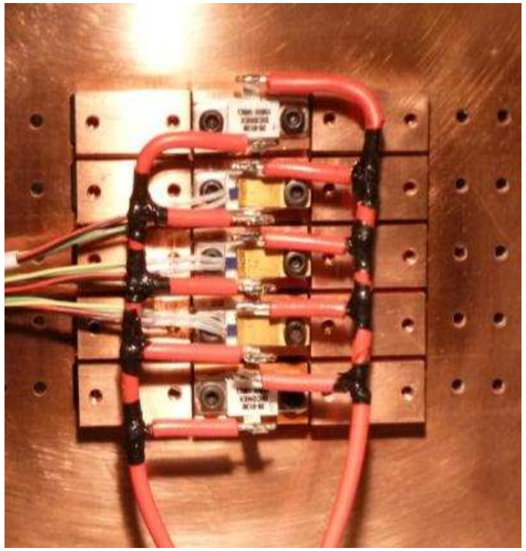
- Cold Plate for 8 x 5 Diode Stacks 25 kW each @ 880nm or 12kW @ 940nm/980nm-1ms pulse
- Up to 1MW Total Peak Power



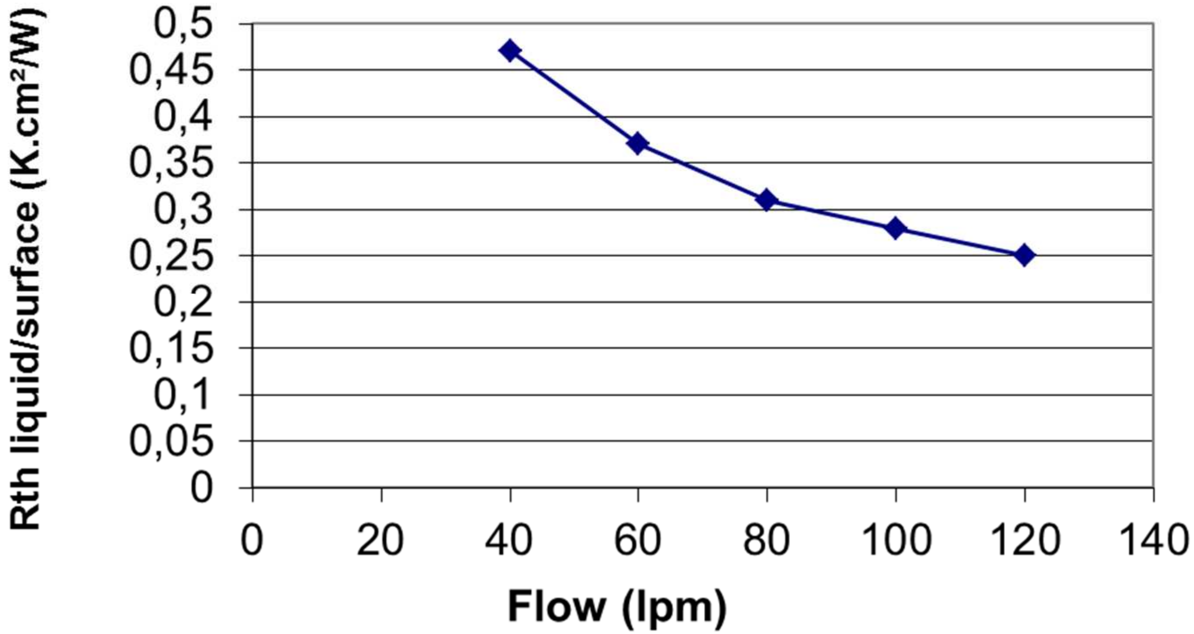
<u>Designed for</u>

- Emitting surface 167x56 mm²
- Optical Gap
  - FA: 1mm
  - SA: 1,5 mm
- > 75% Optical Filling Factor

Cold Plate for 2 D Arrays



- Test with Electrical Resistances
- Rth @120 l/min: 0,25 Kcm^2/W
- ΔT (ptv) @120 l/min, 30 W/cm^2 : 1,1°C



Conclusions

- **Progress in Bar and Packaging Technology!**
  - **➔ Efficiencies of 70% max at 9xx nm**
  - **➔ Peak Power 500W per bar (@ 9xx nm & 880 nm)**
- **Collimation at small bar to bar pitch down to 400µm (880nm)**

Extremely High Brightness stacks

Highly Compact Design ➔ simplifies optical system

- **Stack Assembly: Minimized “Dead Zones“➔ 90% Optical Filling Factor in 1D and 75% in 2D**
- **Outlook: Increasing peak power per bar (costs, brightness)**

BUT :➔ *requires higher efficiencies and at max power*

➔ rethink packaging (Rth, costs)

1. Laser Diode Driver Specifications

- **Compact design 19” 3U**
- **Versatile capabilities**
  - Floating outputs
  - 1 or 2 channels
  - User programmable overvoltage protection
  - Internal or external trigger
- **High Efficiency**
- **User friendly interface**
  - Front panel touch screen
  - Ethernet remote
- **Fully protection of laser diodes:**
  - Over load protection, permanent short circuit
  - reverse polarity
  - Open circuit
  - Safety interlock

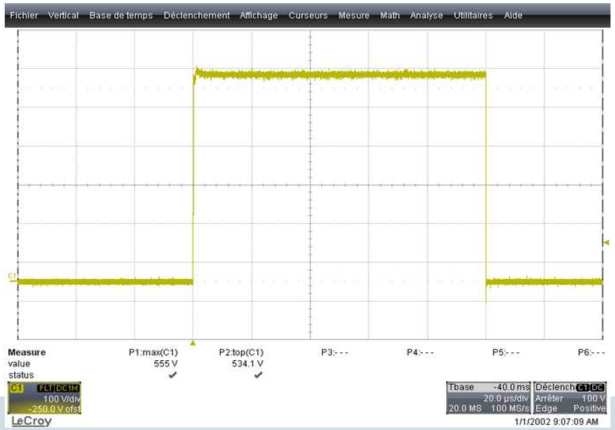
Specifications	
Diode pulsed current	1000A (2 x 500A)
Diode voltage	0 to 100V
Peak power	50kW
Pulse energy	150J max
Pulse duration	20µs to 3ms
Pulse repetition frequency	0 to 500Hz
Average power	1000W
Universal AC input	85-265V_{AC} / 50-60Hz

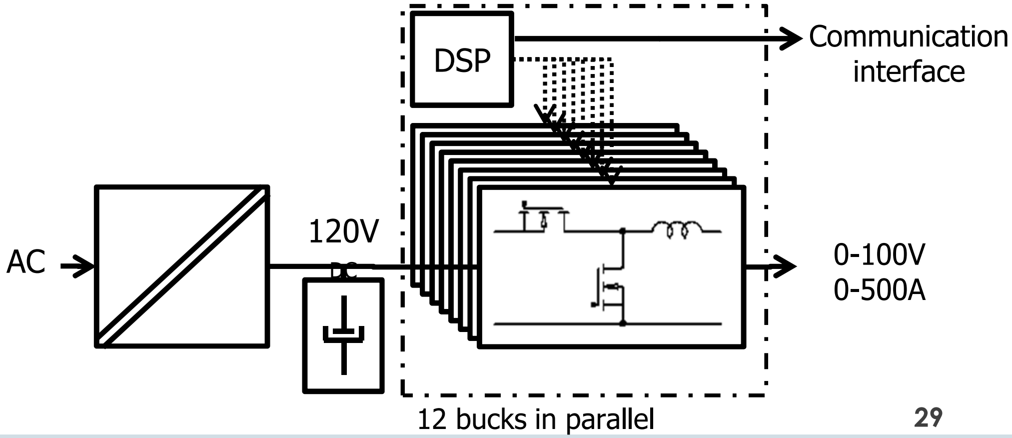
2. Features

- **Pulse shaping with multiphase buck converter**
  - Digital-only regulation with DSP
  - 12 interleaved channels of 46A each
  - Real time Active current balancing between channels
  - Ultra low output capacitance
  - High efficiency >90%

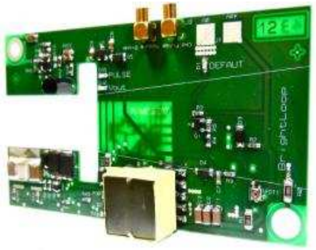
- **Error log / events log**
  - Pulses parameters
  - Measured pulses characteristics
  - Pulses counter

- **Extensive protections: complete FMEA available**





3. Other references



Diode Driver 400A / 10W

- Output : 400A during 100ns
- Frequency repetition : 10kHz
- Compact design, high efficiency

High Voltage Capacitor Charger 3kW

- Three-phase AC input 115 – 480V, PFC
- Output 3 000 J/s, 0 – 3000V
- Serial trigger (25 kV)

Backup Power Supply with Ultracapacitors 8kW

- **Power: 8kW during 0,5s**
- **Charge and discharge management**
- **Digital regulation and command**
- **Discharge current : 320Amax**

Custom designs are welcome !